2010 Phased Array Radar Innovative Sensing Experiment (PARISE)

A Guide for Forecasters

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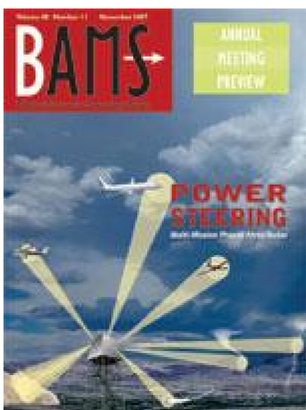

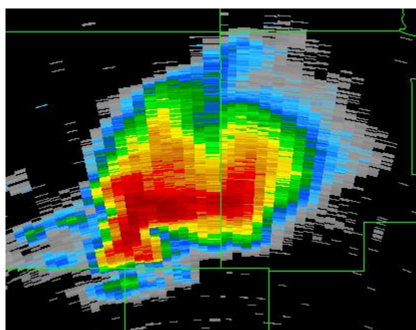

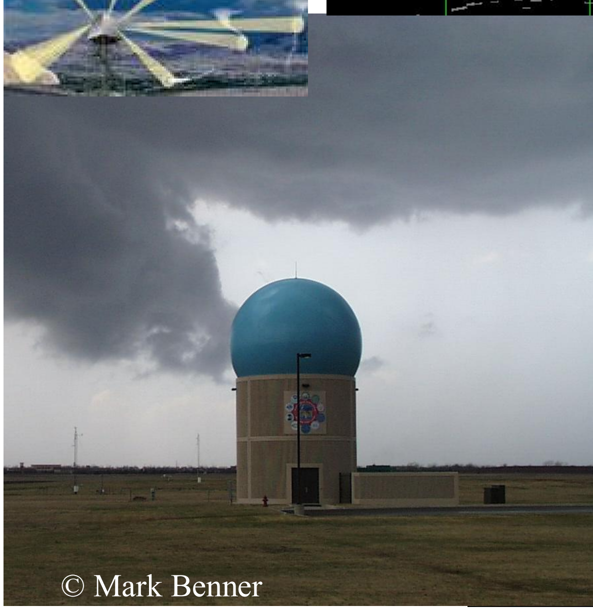

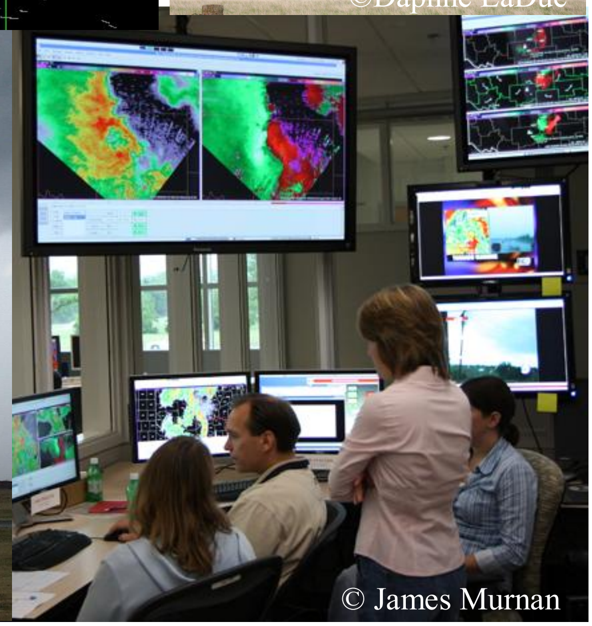

1. Introduction

The year 2008 marked the 20th anniversary of the final design for the Weather Surveillance Radar-1988 Doppler (WSR-88D). This design milestone was preceded by a ~30-year effort focused on the research and development of Doppler weather radars (Whiton et al. 1998). Continuous improvements to the WSR-88D system hardware and products (Crum et al. 1998; Serafin and Wilson 2000) have resulted in significant service improvements, including increased mean warning lead time for tornadoes from 6 to 13 minutes, and reduced tornado-related injuries (40%) and fatalities (45%; Simmons and Sutter 2005). However, the approach of this system toward its 20-year design life cycle (Zrnić et al. 2007), advances in radar technology since the early 1980s, and the lead time involved in the research, development, acquisition, and deployment of new systems have motivated the consideration of a replacement system or family of systems (National Academies 2002, 2008).

As a leader in the development of new weather surveillance capabilities, the National Severe Storms Laboratory (NSSL) and its partners have acquired and fielded an S-band Phased Array Radar (PAR), located on the north campus of the University of Oklahoma. This facility is known as the National Weather Radar Testbed (NWRT). This radar system is unique in that it provides **targeted, high-temporal resolution, electronic scanning** of storms within a 90° azimuthal sector. The NWRT PAR's electronic scanning supports focused sampling of weather without rotating the antenna. A detailed description of this and other PAR capabilities is given in the next sections.

Since spring 2007, the NSSL has invited National Weather Service (NWS) forecasters to participate in experiments designed to demonstrate and provide user feedback on PAR weather surveillance capabilities. The evaluations of PAR data given by previous participants have positively impacted PAR research and development, and we look forward to continuing this successful process during the 2010 Phased Array Radar Innovative Sensing Experiment (PARISE). To stay informed about this experiment and other activities related to the PAR, check the PARISE web site: http://www.nssl.noaa.gov/projects/pardemo.

What is particularly exciting about the 2010 PARISE is that your participation, and subsequent analysis of data collected during the experiment, will provide the *first rigorous assessment* of operational impacts of high-temporal resolution data versus conventional resolution data. During the experiment, you will have the opportunity to evaluate the operational utility of PAR technology during real-time pseudo-operational warning situations, as well as through playback of archived cases.

To help prepare you for these experiences, this document gives an overview of current NWRT PAR characteristics and capabilities (sections 2 and 3), the scanning strategies that will be run during operations (section 4), and an overview of the activities you will be involved in.

2. PAR Characteristics and Capabilities

The NWRT PAR is an electronically steered, S-band radar (for a detailed description, see Zrnić et al. 2007) that was once mounted on a Navy ship. Its SPY-1A antenna forms a beam electronically by controlling the phase of 4,352 transmit/receive elements. The steering of the beam is also accomplished electronically by fixing the beam in a set direction while data is collected along a radial, and then instantly switching the beam to another position.

Because the NWRT PAR was originally developed to track military missiles and airplanes, rather than to detect weather echoes, the radar system transmits vertically polarized electromagnetic waves. Since a raindrop becomes flatter with increasing size, the magnitude of reflectivity returns may be less than those produced using a horizontally polarized beam.

A basic characteristic of phased array radars is variation of the beam width in azimuth due to electronic beam steering. For the NWRT PAR, in the direction perpendicular to the antenna face, i.e., broadside, the beam width is 1.5°, which is similar to the effective beam width of the WSR-88D without azimuthal oversampling (i.e., super resolution). Between broadside and a 45° angle from broadside, the beam width increases gradually to 2.1°. During data collection, overlapped azimuthal sampling is used to provide apparent finer resolution of the increasingly degraded data toward the edges of the sector scan. In an operational system, the beam width specifications would match or exceed those of the WSR-88D.

Currently, the NWRT PAR is a single-faced phased array system which scans a 90° sector while stationary. As a result, the PAR collects data with a VCP 12 scanning strategy, for example, within 58 s rather than 258 s (90° sector vs 360° sector, respectively). The reduction in time required for volumetric updates produces more realistic evolution of storm structures (Heinselman et al. 2008) and eliminates smearing of the beam due to rotation of the antenna. An operational PAR configuration, however, may have 4 independent faces capable of scanning a complete 360° sweep. In essence, a 4-faced PAR would be like having 4 radars in one location, each scanning its own 90° sector. Because the NWRT PAR has only one face, it is mounted on a pedestal to facilitate data collection within the 90° sector containing weather returns of greatest meteorological interest.

Owing to its different antenna design, the NWRT PAR has some unique capabilities compared to the WSR-88D. Most importantly, electronic steering of the beam supports targeted scanning of weather echoes. This spring, targeted scanning of storms will be accomplished using adaptive scanning functionality developed by NSSL, called ADAPTS. The purpose of this technique is to concentrate data collection on areas with significant weather echoes, in order to provide the user with more timely, needs-driven data. As described in the next section, the key radar need afforded by ADAPTS is higher-temporal resolution; an important radar capability reported in several recent studies (OFCM 2006; Steadham 2008; LaDue et al. 2010).

3. ADAPTS: Adaptive Data Signal Processing Algorithm for PAR Timely Scans

ADAPTS is a proof-of-concept implementation of spatially targeted adaptive scanning for the electronically steered NWRT PAR. Initially deployed for the spring of 2009, ADAPTS has demonstrated that the performance improvement with electronic adaptive scanning can be significant compared to conventional scanning strategies, especially when observing isolated storms. In this release, ADAPTS has been enhanced to provide more advanced user control of processing parameters and to work with less traditional scanning strategies.

ADAPTS works by “turning on” or “turning off” individual beam positions within a scanning strategy based on three criteria. If one or more criteria are met, the beam position is declared *active*. Otherwise, the beam position is declared *inactive*. Active beam positions are determined using data from the current scan but do not become valid until the next scan (Fig. 1). Thus, the algorithm is designed to take into account storm evolution between successive scans. The set of active beam positions is updated at the end of every scan. However, new storm developments could be missed due to a particular distribution of inactive beam positions, so ADAPTS periodically completes a full volumetric surveillance scan. A user-defined parameter controls the time between full surveillance scans (by default this is set at 10 min, which is twice the mean update time of NEXRAD precipitation scanning strategies). Following a surveillance scan, data collection continues only on the active beam positions (Fig. 2).

3a. Determination of active beam positions

A beam position becomes *active* if one or more of the following criteria are met:

1. Reflectivities as a function of range (i.e., along the beam) meet continuity, coverage, and significance conditions.
2. The beam position elevation angle is below a predefined level.
3. A “neighboring” beam position is active based on the first or second criteria.

The first criterion uses continuity, coverage, and significance conditions to make a quantitative determination of the amount of significant weather returns at each beam position. In this context, a beam position is active if it contains:

- a certain number of consecutive range gates (by default 4) with reflectivities exceeding a threshold (by default 10 dBZ), and
- a total areal coverage (by default 1 km^2) with reflectivities exceeding the same threshold (the areal coverage is computed as the product of the range spacing and the azimuthal gate width which depends on the distance from the radar and the 2-way, 6-dB effective antenna beamwidth).

The second criterion provides data collection at all beam positions for the lowest elevation angles to continuously monitor low-altitude developments. A user-defined elevation threshold (1.98° by default) controls the lowest elevation angle where ADAPTS may begin to inactivate beam positions.

The third criterion uses “neighboring” beam positions (both in azimuth and elevation directions) to expand the data collection footprint and allow for continuous adaptation in response to storm advection and/or growth. Nevertheless, new developments at midlevels may not be immediately sensed, and additions to the list of active beam positions may be delayed until the next full surveillance scan. Each beam position in a scanning strategy has an associated neighborhood that is defined by a box on the azimuth-elevation plane (Fig. 3). The minimum dimensions of the neighborhood box are defined by four angular distances with respect to the beam position in question (up, down, left and right). The default parameters define a 4.4 deg-by-2 deg box on the azimuth-elevation plane centered on each beam position. However, the neighborhood box is adaptively extended to ensure at least one neighboring beam position in every direction (up, down, left, and right). An additional parameter specifies whether to use a cross or a rectangular domain (cross by default) as illustrated in Fig. 3. It is important to note that in this version of ADAPTS, the "neighborhood" rules are designed to work on scanning strategies with potentially unique azimuthal sampling at every elevation. Additionally, based on the second and third rules only, ADAPTS will always activate all beam positions at and below the elevation threshold plus those at the next higher elevation angle and possibly more depending on the "up" elevation dimension of the neighborhood box (for Oversampled Scanning Strategy defined herein, this is 3.07° by default).

3b. Scanning strategies

For the spring of 2010, ADAPTS was enhanced to work with more general scanning strategies. That is, ADAPTS only assumes that the scanning strategy runs in PPI mode (i.e., constant elevation scans) for azimuthal sectors between 1 and 90 deg with a minimum azimuthal spacing of 0.5 deg (i.e., the maximum number of beam positions in an elevation is 180). However, unlike the previous version of ADAPTS, this version does not require having one scanning strategy that repeats continuously, tilts that are defined in ascending elevation order, or the same beam position azimuths on every tilt.

3c. Monitoring ADAPTS performance

Users at the Radar Control Interface (RCI) can monitor the performance of the ADAPTS algorithm by looking at a graphical display of active beam positions (Fig. 4). Beam positions are color-coded as follows: white beam positions are inactive, green and yellow beam positions are active. Green beam positions meet the first and second detection criterion, whereas yellow beam positions correspond to the "neighbor" footprint extension (third criterion). The display updates every second and highlights in red the "current" beam position.

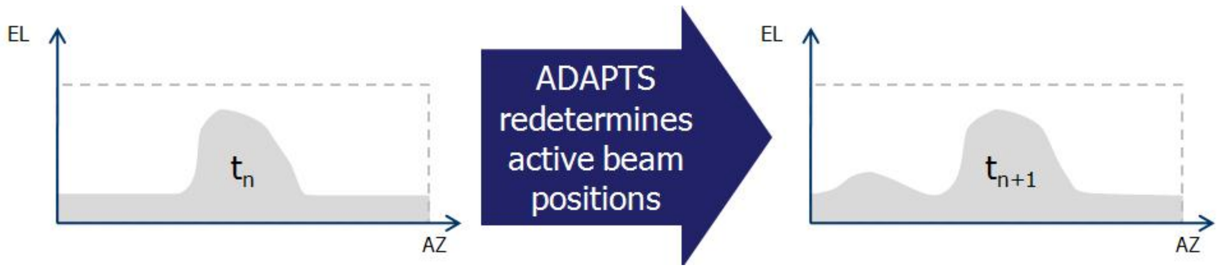

Fig. 1. ADAPTS uses the set of active beam positions from the current scan (at time t_n) to determine the set of active beam positions for the next scan (at time t_{n+1}). That is, the set of active beam positions is updated after every scan.

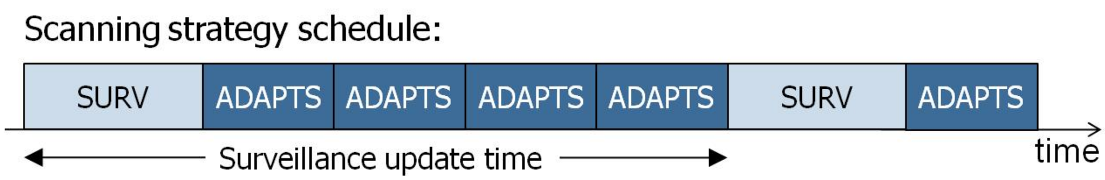

Fig. 2. A full surveillance scan (SURV) is interleaved periodically to capture new developments that may have been missed in the ADAPTS scans.

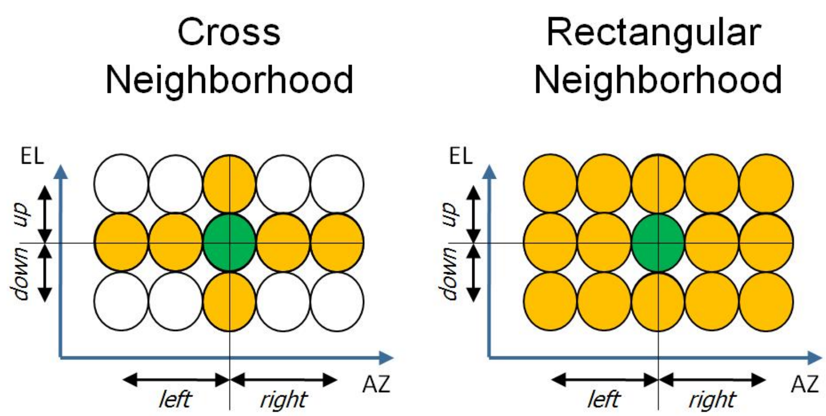

Fig. 3. Example of cross and rectangular neighborhoods used to grow the set of active beam positions to account for storm evolution between scans. The neighborhood box on the azimuth-elevation plane is defined by four parameters relative to the beam position under analysis: left, right, up, and down. In these figures, the green circle depicts the beam position under analysis, orange circles depict neighboring beam positions, and white circles depict non-neighboring beam positions.

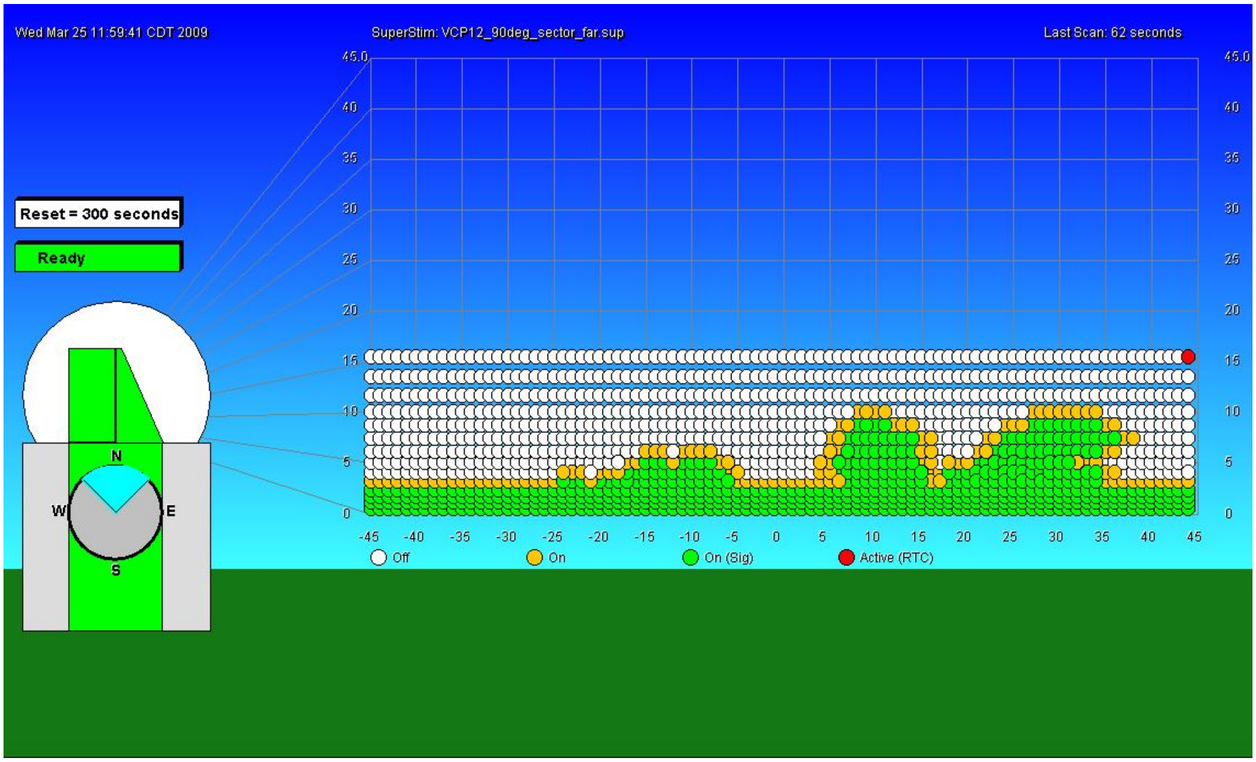

Fig. 4. Screen capture of the RCI graphical display of active beam positions with ADAPTS.

4. Oversampled scanning strategy

An important objective of PARISE is the development and testing of scanning strategies designed to provide enhanced sampling of processes key to the development of hazardous weather. To meet this objective, we have developed an oversampled scanning strategy that provides optimized sampling in elevation and azimuth, good data quality, and faster update times than conventional scanning strategies. Subsets of this scanning strategy may be used to improve update time when storm coverage is limited or tornadoes are forecast as imminent.

Originally defined by Brown et al. (2000), optimized vertical sampling occurs when the "maximum height uncertainty (expressed in percent of true height) is essentially the same at all ranges and for all heights of storm features." Optimized vertical sampling provides denser sampling at low altitudes, where it is needed most. The oversampled scanning strategy has a maximum height uncertainty of 18% and PRTs are chosen to sample storms with heights up to 18 km above ground level (AGL) through a minimum range of 20 km from the NWRT PAR. These criteria result in a VCP with 22 elevations (Fig. 5).

Similar to super-resolution sampling (Brown et al. 2005), 50% overlapped azimuthal sampling (0.75–1.05°) is employed to improve the apparent resolution of azimuthal signatures sampled by the NWRT PAR. Because the beam width varies across the sector, the oversampling is adjusted accordingly. The number of azimuthal beam positions is 55 without oversampling, and increases to 109 beam positions with the 50% oversampling employed here.

Data quality of the moments is related to the number samples. In the oversampled scanning strategy, the number of samples matches or exceeds those of VCP 12 (NOAA 2006). Other data quality issues, such as ground clutter, attenuation, and noise are addressed by a suite of algorithms described by Torres et al. (2010). Batch-like processing is run below 6° elevation to minimize range-folded weather returns.

The set of beam positions (elevations and azimuths), and number of samples defined above, provide a baseline scanning strategy whose update time is about 2 min. If range oversampling (Torres and Zrnić 2003) is employed, the sampling time would be reduced to about 1 min, while maintaining similar data quality. This technique is currently being evaluated and may be implemented while you are in Norman. If so, the update times given in this document would be reduced by about 50%. Besides providing comprehensive sampling of storm structure, a goal of the PARISE is to provide needs-driven update times. One of these needs is rapid update times. As mentioned in section 3, update time is minimized automatically by ADAPTS, by sampling only beam positions where weather signals are present (above ~ 3.5°). This spring, update time will also be minimized by manually scheduling subsets of the oversampled VCP (Table 1).

When storms are located within only 120 km of the NWRT PAR, update times are reduced via a modified version of the oversampled VCP. In the modified VCP, the waveform is changed from batch to uniform, and all PRTs are set to 800 μs. These changes reduce update time from 2 min to 1.4 min. To check for new storm development beyond 120 km, an 11-elevation surveillance scan can be run. In addition to location-based modification of the oversampled VCP, a severe weather-based modification is available in situations where tornadogenesis is possible.

If tornadogenesis is possible (e.g., supercells or QLCSs are occurring), number of elevations in the oversampled VCP may be reduced to either two or four, based on storm range. The small number of elevations is chosen to sample low altitudes and provide the significantly faster updates needed to sample tornadic vortex signatures and other circulations that evolve on short time scales.

When storms are located more than 120 km in range from the NWRT PAR, the two lowest elevations of the oversampled scanning strategy are employed, resulting in 22 s updates. In all other cases, the four lowest elevations are used. This four-elevation-version of the oversampled VCP produces 38 s updates. To further improve update time, if storms are located only within 120 km of the NWRT PAR, a uniform waveform is employed, reducing update time for 4 tilts from 38 to 18 s. In operations, this set of tornadic VCPs will interlaced with the appropriate version of the oversampled VCP to provide intermittent sampling of the full storm (or volume).

The interlacing is done so that the range-sensitive tornadic VCP runs for about 1 min, followed by the appropriate version of the oversampled VCP.

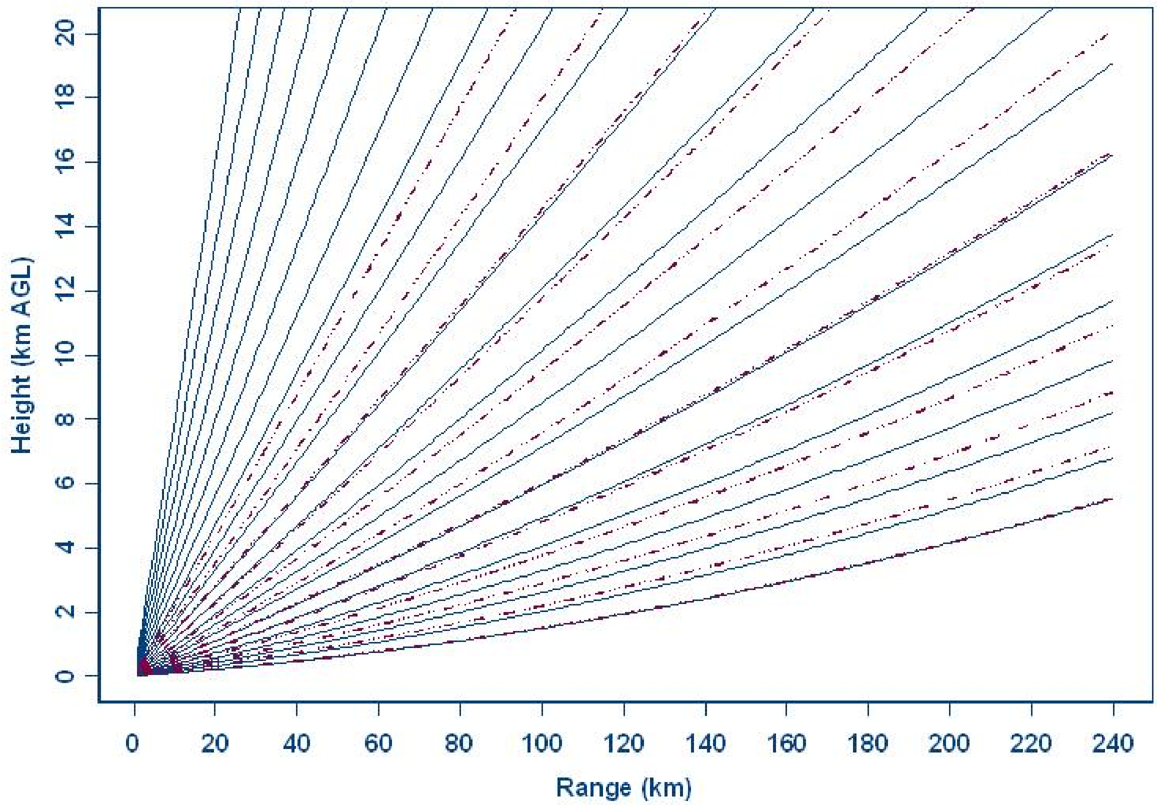

Fig. 5. Range-height plot of elevation angles defining oversampled scanning strategy with 18% height uncertainty (blue lines). Elevation angles of VCP 12 are shown for comparison (red dash-dot lines).

Table 1. Basic description of VCP attributes.

VCP	# Tilts	Waveform	Update Time (min)
Oversampled_VCP	22	Split cut < 6°	2
Oversampled_VCP_within_120km_only	22	Uniform	1.4
Tornadic_outside_120km_only	2 + 22	Split cut	3.3
Tornadic	4 + 22	Split cut	2.73

Tornadic_within_120km_only	4 + 22	Uniform	2.3

5. Forecaster Activities during PARISE

As stated in the introduction, what is particularly exciting about the 2010 PARISE is that your participation will play a key role in producing the *first rigorous assessment* of operational impacts of high-temporal resolution data versus conventional-resolution data. The official data collection for this assessment will be on Thursday from 9 am – 5 pm. On Tuesday, you will have the opportunity to begin gaining experience using the Warning Decision Support System – Integrated Information (WDSS-II; Lakshmanan et al. 2007) and providing critical feedback for PAR developers by analyzing NWRT PAR data. The cases analyzed will be real-time or playback, depending on the weather, and you will work them in pairs. For both playback and real-time events, you and your partner will analyze the incoming data and make warning decisions. During real-time weather, a radar operator will run the NWRT PAR for you. Your anticipated schedule is described in Appendix A.

On Tuesday afternoon (1 pm) you will receive a briefing on the NOAA Hazardous Weather Testbed/ Experimental Warning Program and the 2010 PARISE. The briefings will be followed by hands-on training on WDSS-II. After gaining some experience with WDSS-II, you'll get to stretch your legs with a tour of the National Weather Center. If no moist convection is occurring or forecast, we will then go out to dinner as a group. Otherwise, we'll order in food. Either way, after dinner you will build experience using WDSS-II and analyzing PAR data with either playback or real-time data. During the event, you both analyze the data and make warning decisions. We will wrap-up the day with a discussion (debriefing) about your experience.

On Wednesday your day will begin at 1 pm with a presentation on the *Warn-on-Forecast* concept by an NSSL scientist. Rapid-update PAR data and other observations play an important role in data assimilation and modeling efforts that are investigating the potential to make warnings based on forecasts rather than real-time data. Definitely an interesting topic. By 2 pm, we will turn our attention back to PARISE through a participant-led weather briefing (that's you!), followed by another PAR playback or real-time case, and group discussion on your experience. After our discussion, you will have time to eat your dinner. Thereafter, you will analyze your last NWRT PAR playback or real-time case before the Thursday finale. As before, your day will end with a discussion on your experience with the NWRT PAR data.

On Thursday your work day will begin at 9 am. During the day you will form two groups to analyze two different events; one will be in the morning and the other in the afternoon. The rigor in assessment is here: one group will be the control and the other the experimental group, the difference being which group has full temporal PAR data. Groups will switch roles in the afternoon. Each event will be followed by a group discussion about your experience where you help us determine the potential operational impact of high-temporal resolution PAR data on warning decision making.

On Friday we will meet from 9–11 am to talk about your experiences during the 2010 PARISE. If desired by participants, some of that time will be used for you to share your research with the Norman weather community.

After 11 am, you will be free to begin your travel home.

Acknowledgments: There are many people behind the scenes who make PARISE possible. We thank Mark Sessing for producing the WES simulations; Igor Ivic, Chris Curtis, and David Warde for developing the suite of signal processing techniques to improve the data quality of the NWRT PAR; Ric Adams, Eddie Forren, David Priegnitz, and John Thomson for NWRT PAR software development and testing; Charles Kerr for developing the WarnGen-based interface for WDSS-II; Greg Stumpf and Travis Smith for spearing heading travel and other arrangements for participants; and Kevin Manross for producing the temporally degraded VCPs.

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Appendix A: PARISE 2010 Draft Schedule

Monday
Participants arrive in Norman; on their own for meals, etc.

Tuesday (1 pm – 9 pm)
1 pm Welcome, Introductions, and Briefing on History/Purpose of NOAA Hazardous Weather Testbed (Pam H., Greg S., and Travis S.)

1:30 Overview of 2010 PARISE
2:45 Gain Experience Using Warning Decision Support System – Integrated Information

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4:00 Tour of National Weather Center

5:00 Group Dinner at NWC or nearby (weather dependent)

6:30 Build experience using WDSS-II with either real-time or playback PAR events
8:00 Discuss experience w/ NWRT PAR data
9:00 End of Day

Wednesday (1 pm – 9 pm)
1 pm Presentation on *Warn-on-Forecast* (Dusty Wheatley and David Stensrud)
2:00 Weather briefing by participants.
2:30 Playback PAR events or real-time weather
4:30 Debrief event(s)

5:00 Dinner

06:00 Playback PAR events or real-time weather
08:00 Debrief event(s)
09:00 End of Day

Thursday (9 am – 5 pm)
9 am Preparation for experiment
9:20 Move to room(s) where experiment will take place
9:40 Begin situational awareness of Case#1
10:00 Write Area Forecast Discussion
10:15 Start Case
11:00 Individual Debriefing
11:30 Group Debriefing

Lunch

1:30 Short group meeting
1:45 Move to room(s) where experiment will take place

2:00 Begin situational awareness of Case#1
2:20 Write Area Forecast Discussion
2:35 Start Case
3:35 Individual Debriefing
4:05 Group Debriefing
End of Day

Friday (9 – 11 am)
9 am Debrief week's experiences
11:00 Time to go home!